Bering Strait - the Pacific Gateway to the Arctic

25 years (1990-2015) of year-round measurements in the Bering Strait

- what do we know, and what do we still NOT know?

Rebecca Woodgate
University of Washington

NSF-AON project, with
co-PIs: An Nguyen and Patrick Heimbach *MIT/Univ of Texas Austin*
Collaborators: Julie Raymond-Yakoubian, *Kawerak, Inc*

Prior funding from NSF, ONR, NOAA-RUSALCA, and collaborations with T.Weingartner, K.Aagaard, R.Lindsay, & T.Whitledge. Thanks to J.Johnson, D.Leech, S.Danielson, K.Runciman, C.Ferriz, W.Ermold, M.Schmidt &crews of the Alpha Helix, Laurier, Sever, Lavrentiev, Khromov, & Norseman2

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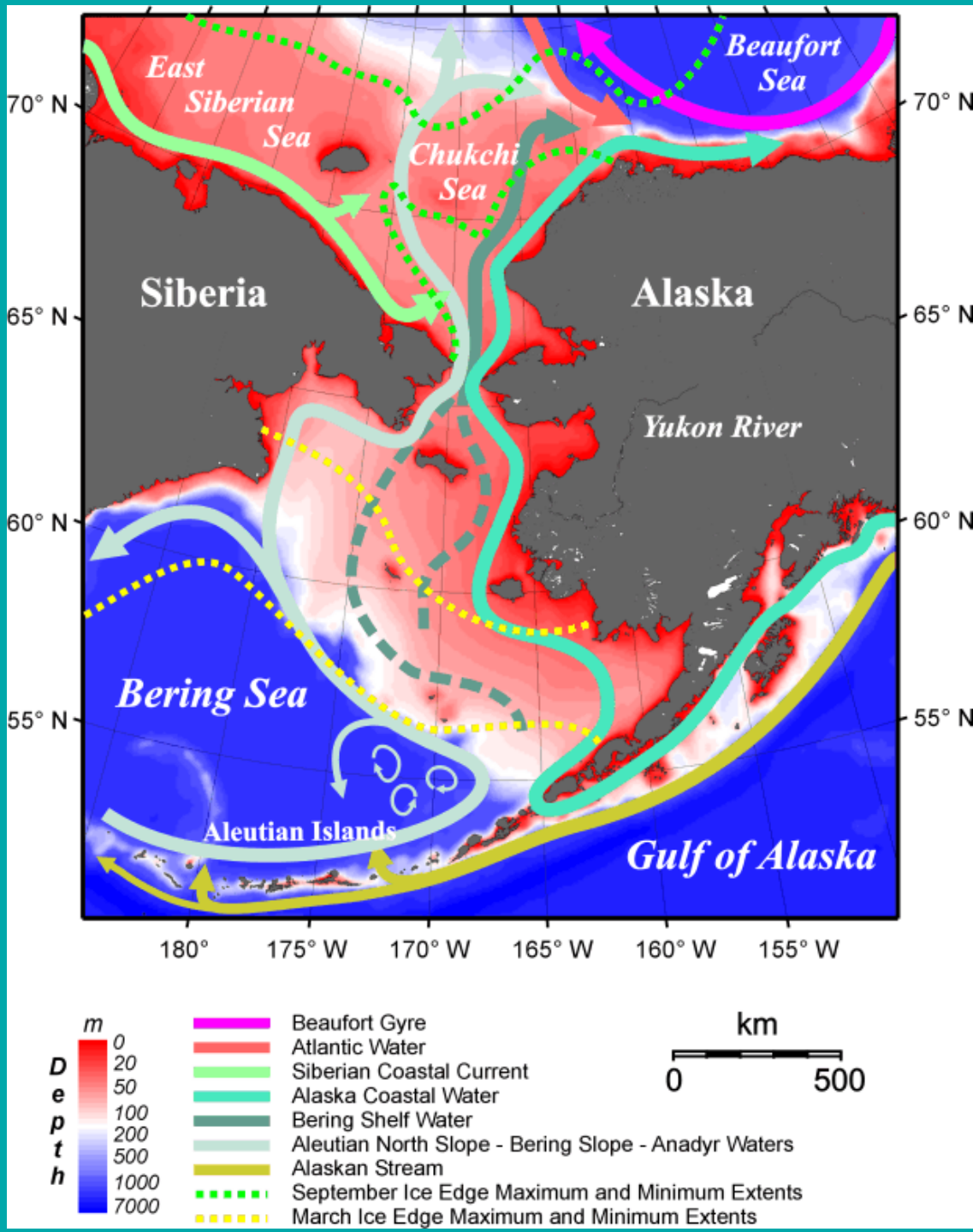
Why care about the Bering Strait?

AON measurements
- What are we doing?
- What are we finding?

Where next?
- products, unknowns, future …

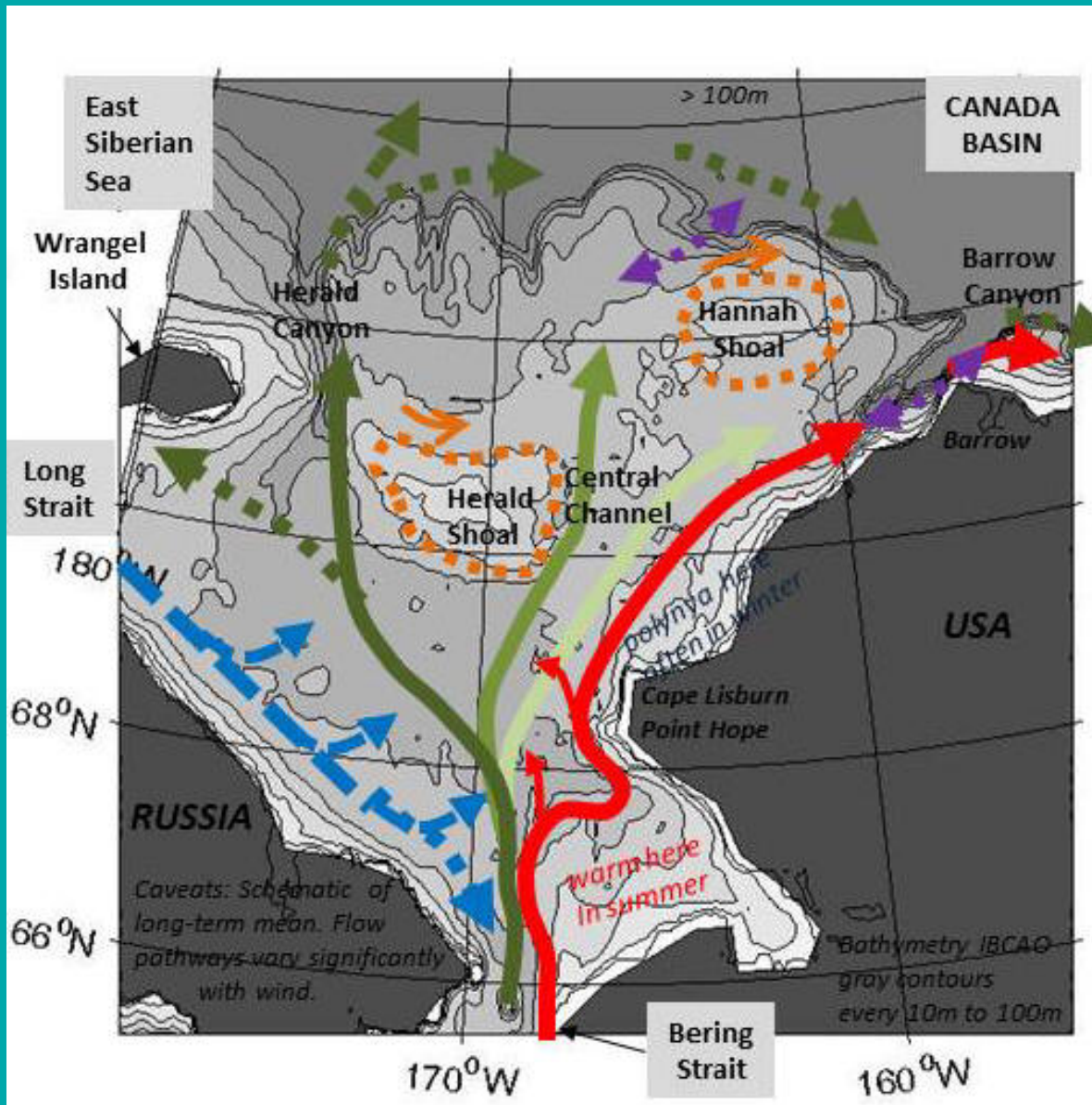
Bering Strait - the Pacific Gateway to the Arctic

... drains the Bering Sea Shelf



Weingartner & Danielson, UAF

... dominates the water properties and flow of the Chukchi



Bering Sea Water, made up of nutrient–rich Anadyr Water (in west, dark green) and lower nutrient Bering Shelf water (lighter greens)
- Exits Arctic via Barrow Canyon, Central Chann Herald Canyon, and maybe Long Strait.
- Some follows shelf break to east, some moves into Canada Basin

Alaskan Coastal Current
- fresh, warm
- present summer to late fall
- loses water to central Chukchi

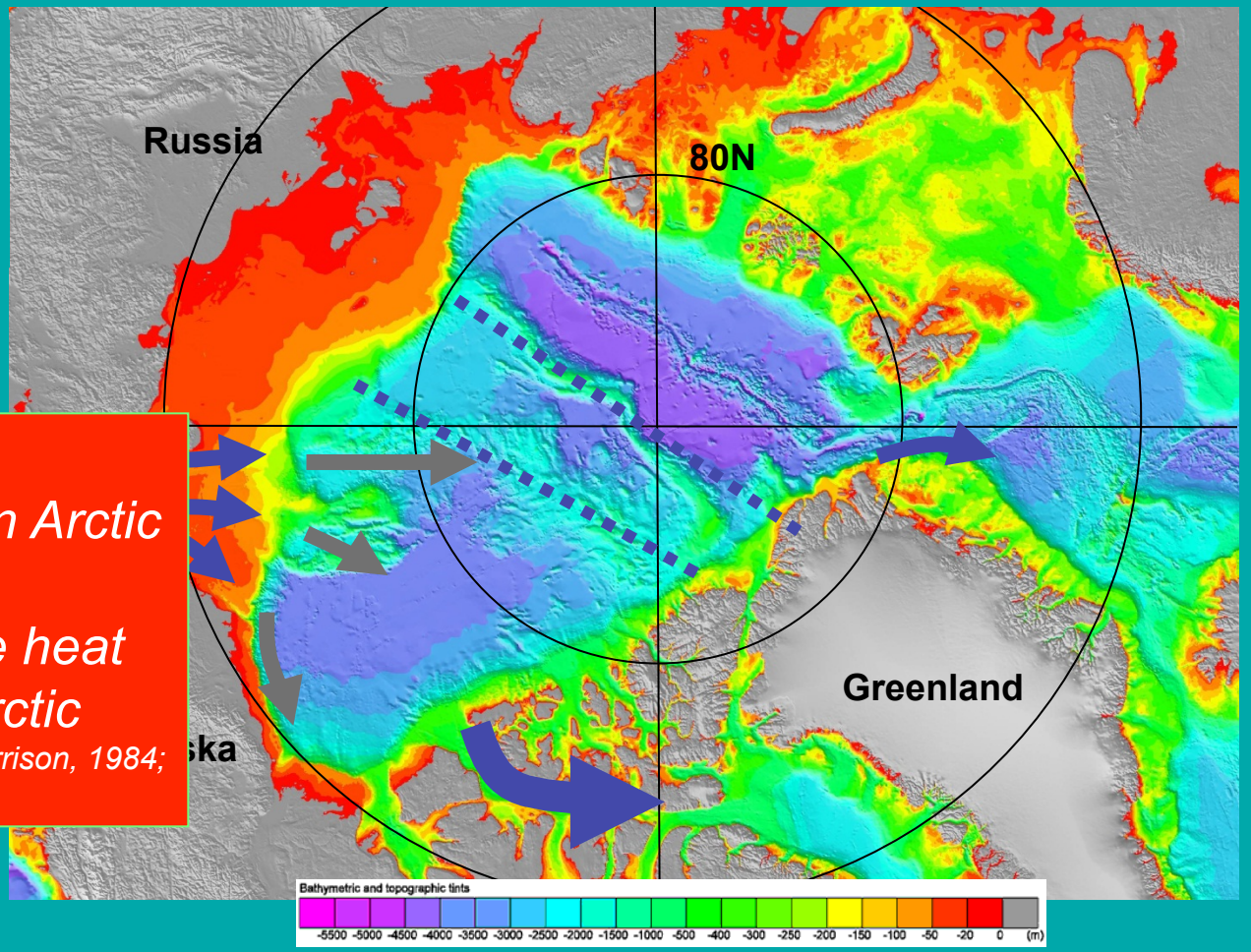
Siberian Coastal Current
- fresh, cold
- present some summers
- may reach Bering Strait, or may exit into central Chukchi

Likely **topographically trapped anticyclonic (clockwise) circulations** over Herald and Hannah Shoal, (Topography may be inaccurate here.)

Upwelling up shelf break canyons brings Arctic waters up onto Chukchi Sea. E.g.,

Woodgate et al, 2005; figure from Hunt et al, 2013, JMS; also psc.apl.washington.edu/HLD

... influences ~ half of the Arctic Ocean



Heat to melt ice

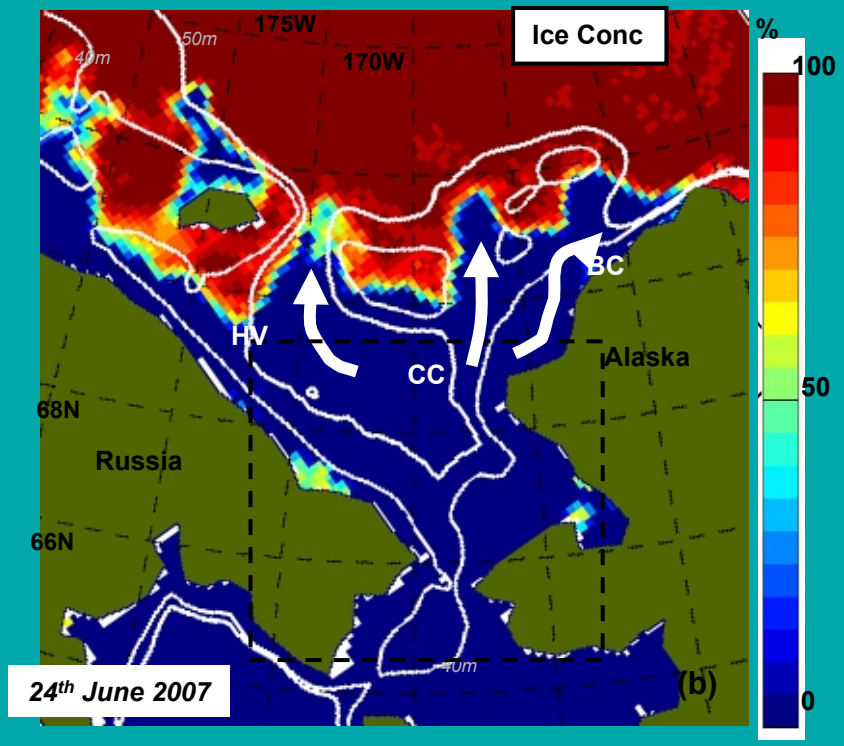
In spring, trigger western Arctic melt onset

Year-round subsurface heat source in ~ half of Arctic

(Paquette & Bourke, 1981; Ahlnäs & Garrison, 1984; Woodgate et al, 2010; 2012)

Figure from Woodgate et al, 2013

Ice Edge reflects flow Pathways



Woodgate et al, 2010

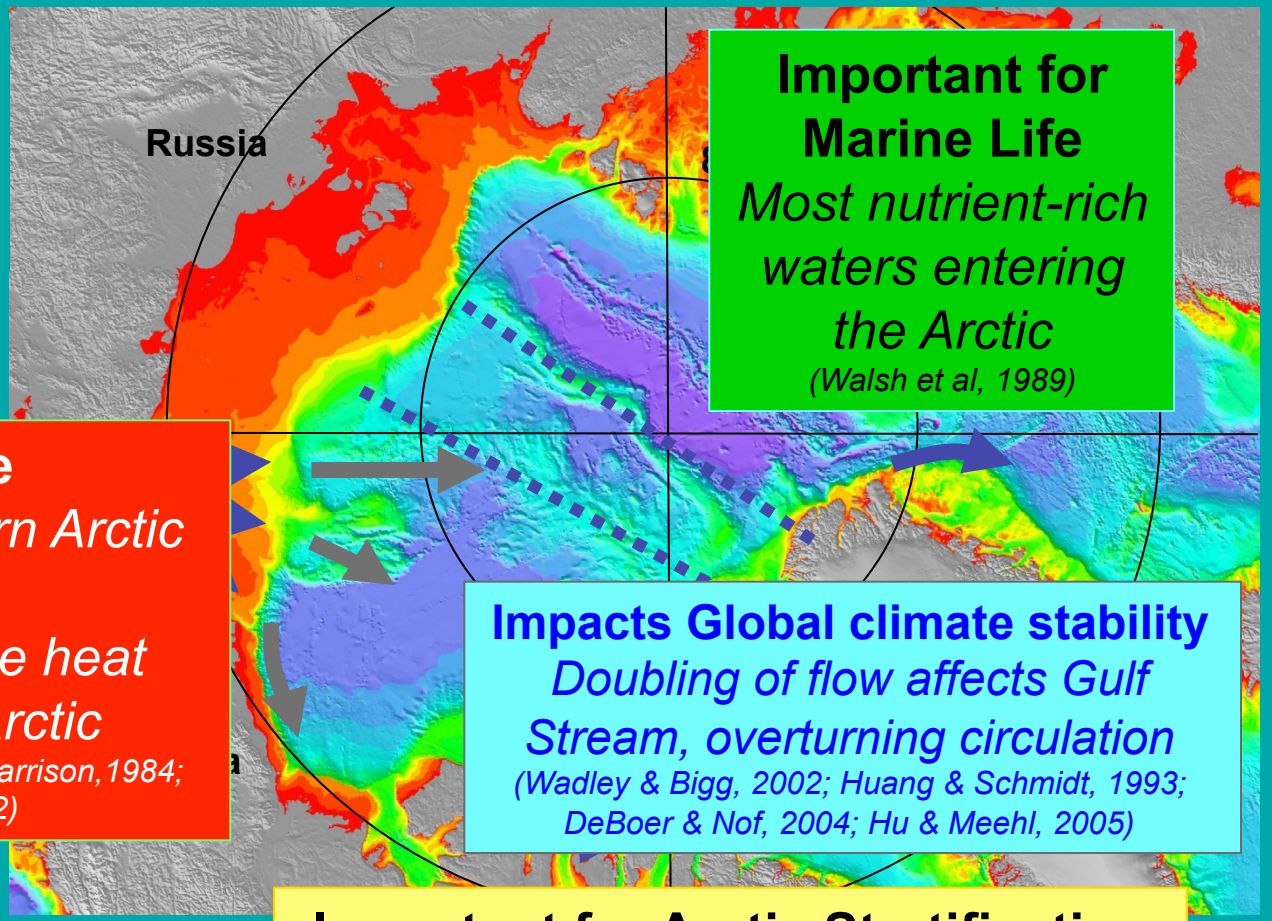
Oceanic heat flow (topographically steered) triggers sea ice retreat onset

Bering Strait Oceanic heat flux is ~ 1/5th to ~ 1/3rd of the Fram Strait oceanic heat flux

Comparable to solar shortwave input to the Chukchi Sea

Woodgate et al, 2010; 2012;

... influences ~ half of the Arctic Ocean



Important for Marine Life

Most nutrient-rich waters entering the Arctic

(Walsh et al, 1989)

Heat to melt ice

In spring, trigger western Arctic melt onset

Year-round subsurface heat source in ~ half of Arctic

(Paquette & Bourke, 1981; Ahlnäs & Garrison,1984; Woodgate et al, 2010; 2012)

Impacts Global climate stability

Doubling of flow affects Gulf Stream, overturning circulation

(Wadley & Bigg, 2002; Huang & Schmidt, 1993; DeBoer & Nof, 2004; Hu & Meehl, 2005)

Significant part of Arctic Freshwater Budget

~ 1/3rd of Arctic Freshwater

Large (largest?) interannual variability

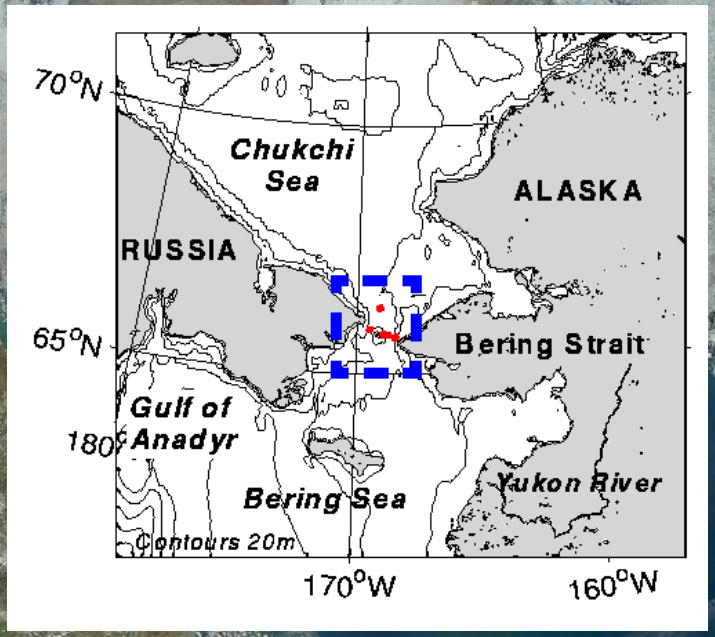
(Wijffels et al, 1992; Aagaard & Carmack, 1989; Woodgate & Aagaard, 2005)

Important for Arctic Stratification

In winter, Pacific waters (fresher than Atlantic waters) form a cold (halocline) layer, which insulates the ice from the warm Atlantic water beneath

(Shimada et al, 2001, Steele et al, 2004)

Figure from Woodgate et al, 2013



BERING STRAIT

~ 85 km wide

~ 50 m deep

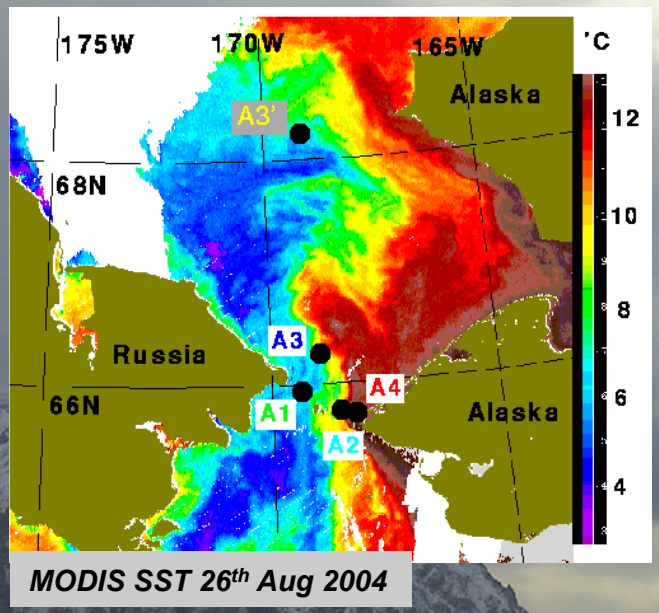
-divided into 2 channels by the Diomede Islands

- split by the US-Russian border

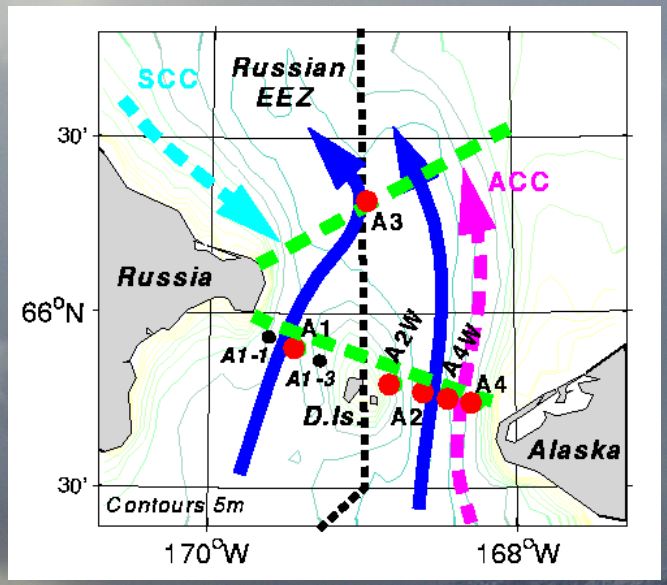
-ice covered from ~ January to April

8th July 2010 Ocean Color
oceancolor.gsfc.nasa.gov
(from Bill Crawford)

Overview of Bering Strait measurements



MODIS SST 26th Aug 2004

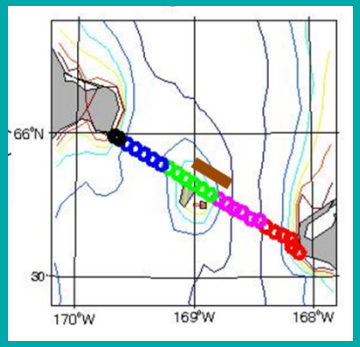


1990 - present
== year-round moorings in US mid-channel
== mostly near bottom
== 2001 started measuring the Alaskan Coastal Current with A4.

Early 1990s, 2004-2006
== 1 (or 2) moorings also in Russian waters.

2007-2011/2012
== up to 8 moorings in the "high-resolution" US-Russian array

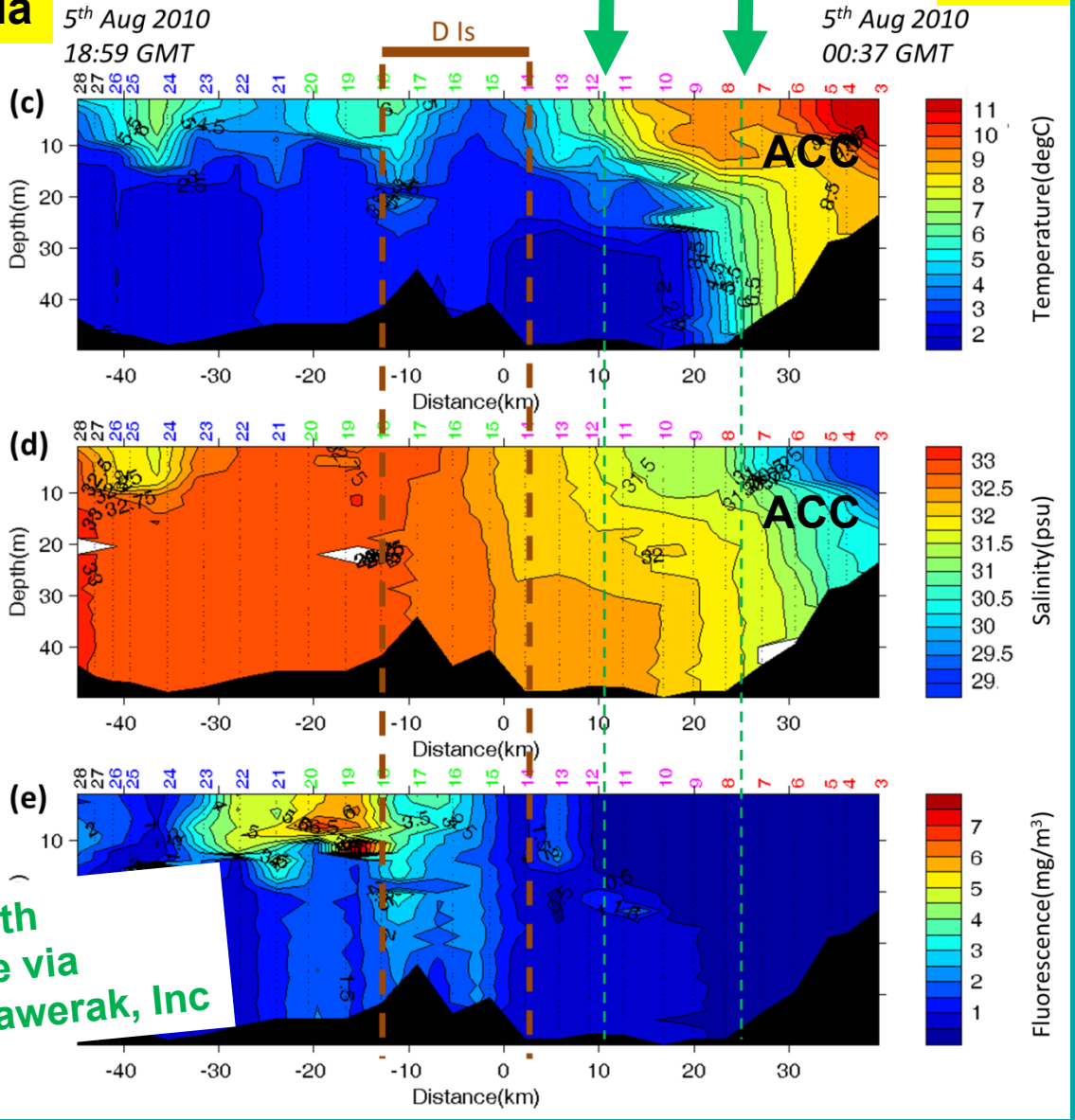
Spatial variability in water properties (Woodgate et al, 2015, TOS)



Russia

Looking North through the Bering Strait

USA



Water properties

- winter ~ homogeneous,
- summer two layer + Alaskan Coastal Current (ACC)

Velocity

- well correlated through the strait (0.95, *Woodgate et al, 2005, DSR*)
+

Features matter as to WHERE you measure

Map features with Native Knowledge via Raymond-Yakoubian, Kawerak, Inc

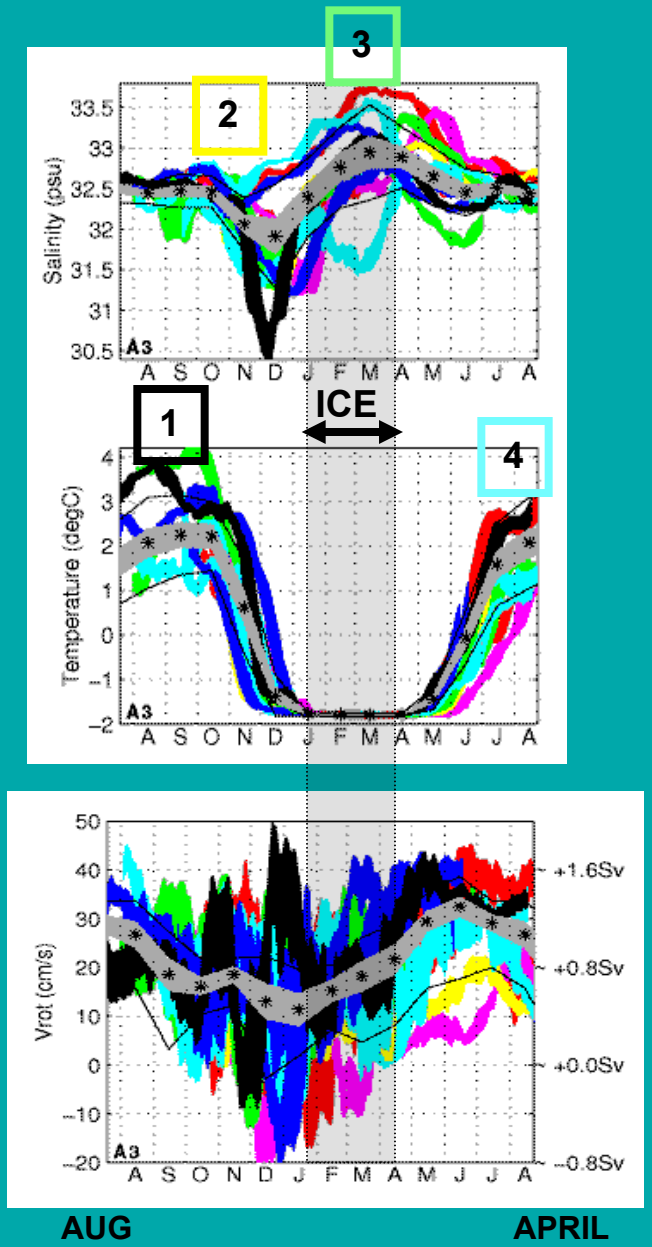
Seasonal cycle in water properties (Woodgate et al, 2005)

Large seasonal (and daily, hourly) variability – thus, for interannual, need to measure year-round

TEMPERATURE
-1.8 to 2.3 deg C

TRANSPORT
0.4 to 1.2 Sv
Annual mean
~ 0.8Sv

(30 day means)



WHY CARE?

Seasonally varying input to the Arctic Ocean

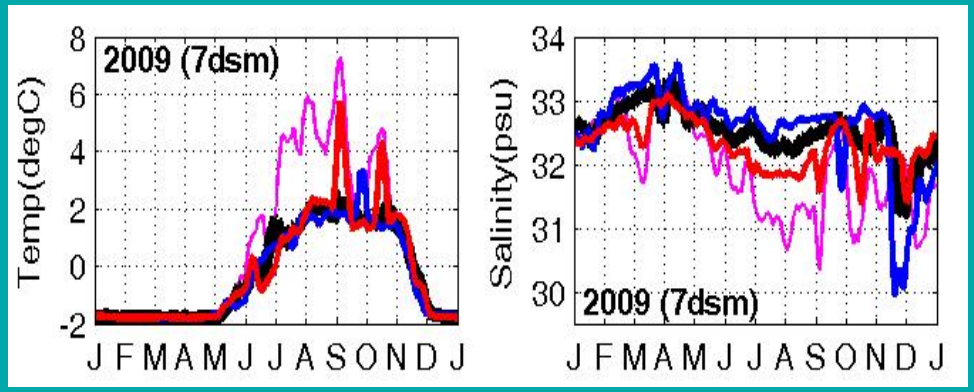
- temperature
- salinity
-volume

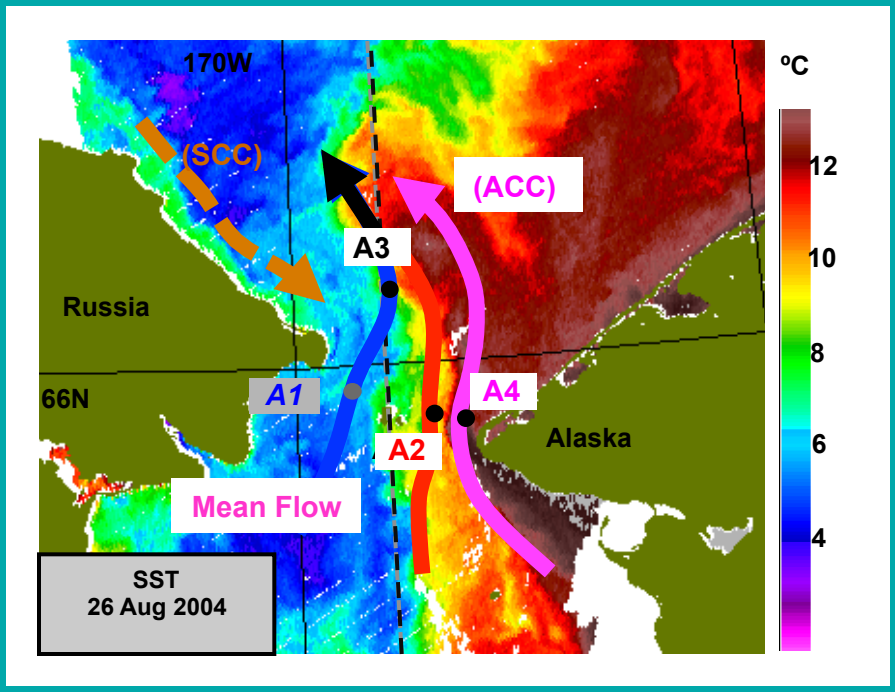
- equilibrium depth (~50m in summer ~120m in winter)

-nutrient loading

The 3-mooring scheme for the Bering Strait throughflow

Prior data show can quantify **physical** fluxes, using only 3 US moorings A2,A3,A4





Velocity

- well correlated at all sites

Temperature & salinity

- A3 (climate site, black) is a useful average of channel flows, i.e., A1 (blue) & A2 (red)

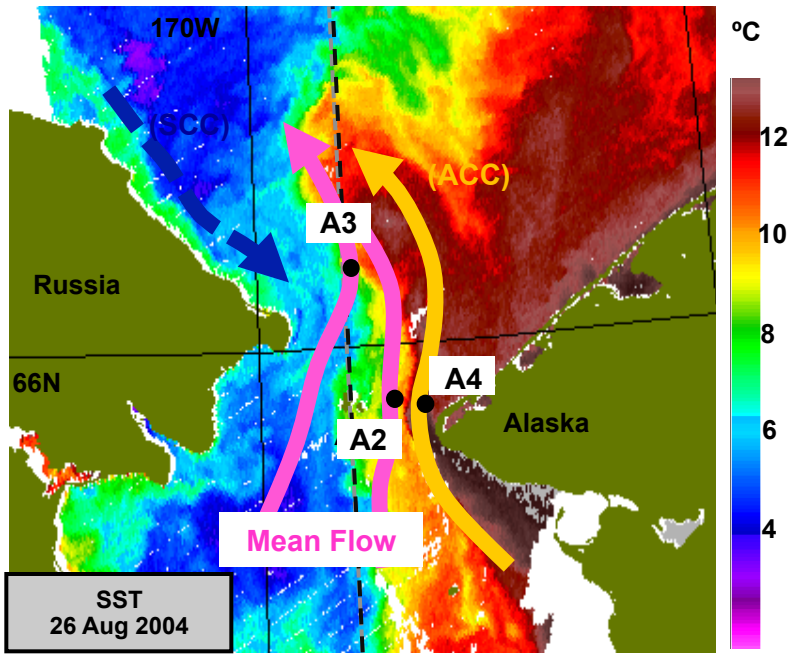
(Can infer A1 properties to ~ 0.1ºC and 0.2psu from A3 & A2)

Must also measure A4, Alaskan Coastal Current (ACC)

~ 1/3rd of total heat flux

~ 1/4 of total freshwater flux

NSF-AON Bering Strait Moorings 2014 - 2018



= Velocity (from ADCP) at multiple depths **from bottom to near surface**

= Lower (~40m) and upper (~15m) layer temperature and salinity

= Sea-ice velocity and thickness

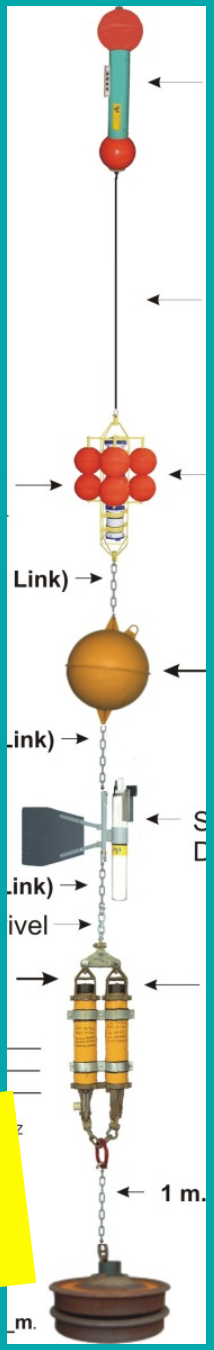
Moorings also carry
- marine mammal recorders (Stafford)
- opportunistic chemistry sensors (Juraneck)

Annual servicing

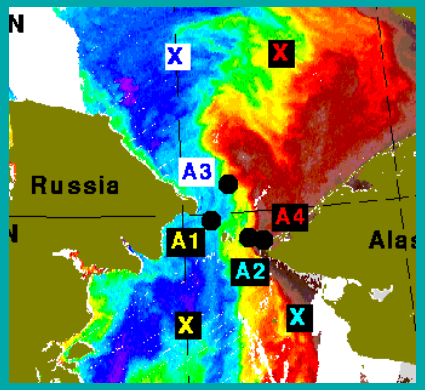
== 3 moorings in US waters to measure
- water and ice properties ~ hrly year-round
- volume, freshwater and heat fluxes
- seasonal and interannual change

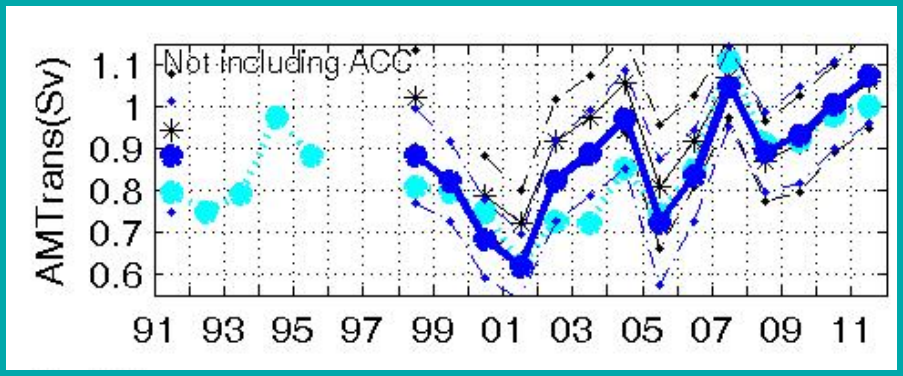
Continuity of this now 25-year Arctic Ocean time-series at a time of critical system change

Your instrument here?



~50% increase in annual Bering Strait throughflow from 2001 to 2011





Significant (~50%) increase in transport

2001 ~ 0.7 Sv (~ 8months flushing)

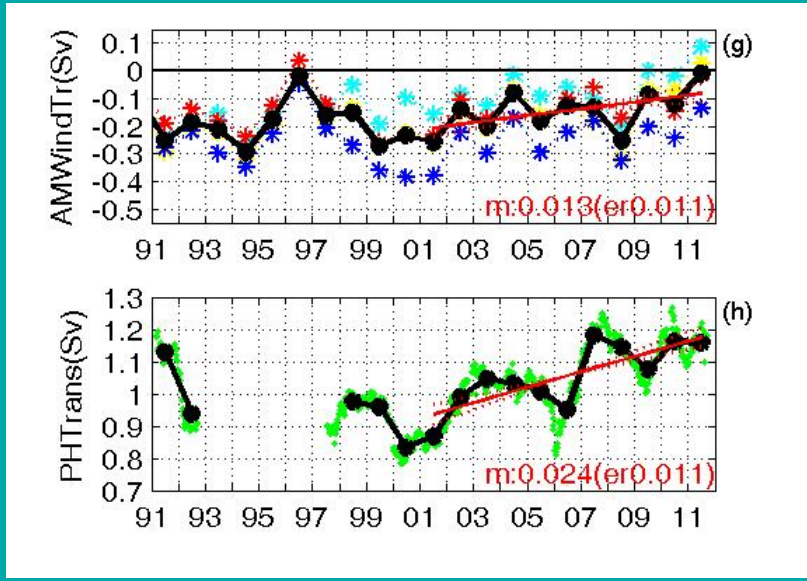
2011 ~ 1.1 Sv (~ 5months flushing)

What drives the change?

~ 1/3rd due to changes in wind

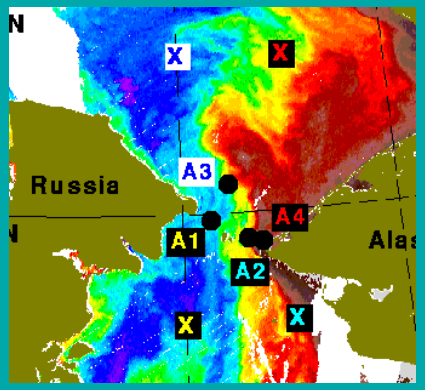
~ 2/3rds due to Pressure Head

(i.e. can't infer from the wind)

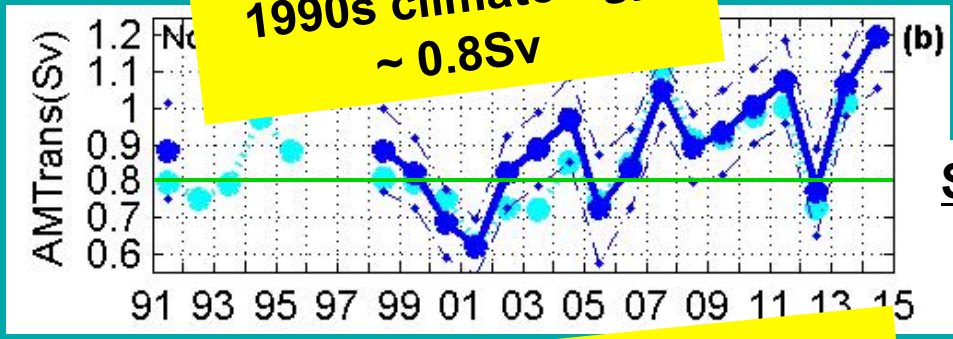


Woodgate et al., GRL 2012

~70% increase in annual Bering Strait throughflow from 2001 to 2014



Significant shift from 1990s climatology ~ 0.8Sv



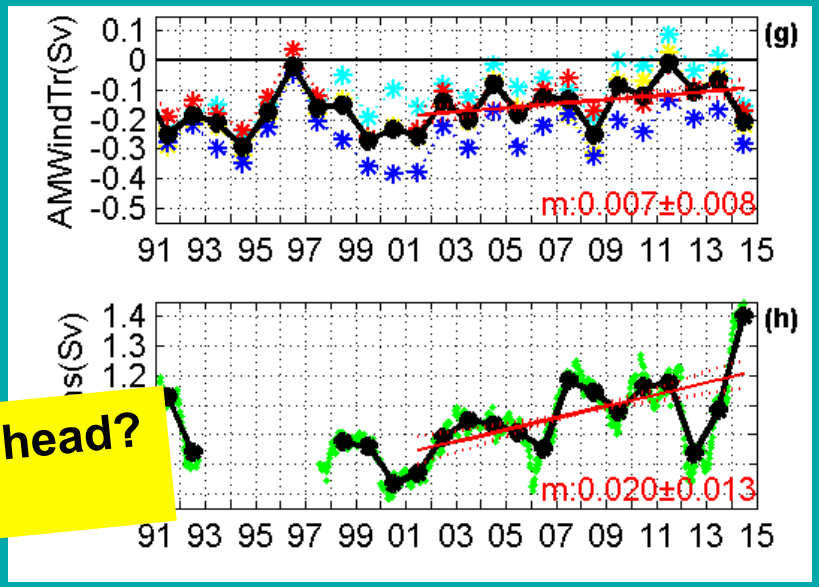
Significant (~70%) increase in transport

2001 ~ 0.7 Sv (~ 8months flushing)

2014 ~ 1.2 Sv (< 5months flushing)

Increasing trend continuing

Why is 2012 so low?



What drives the change?

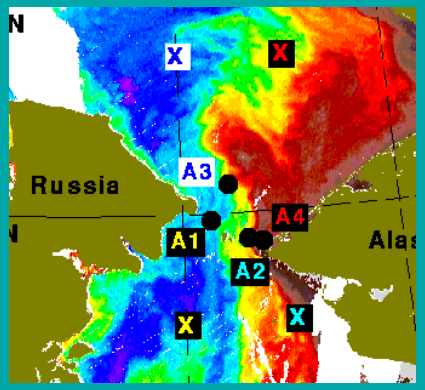
== interannual variability mostly due to Pressure Head (~80% for 2001 to 2014)

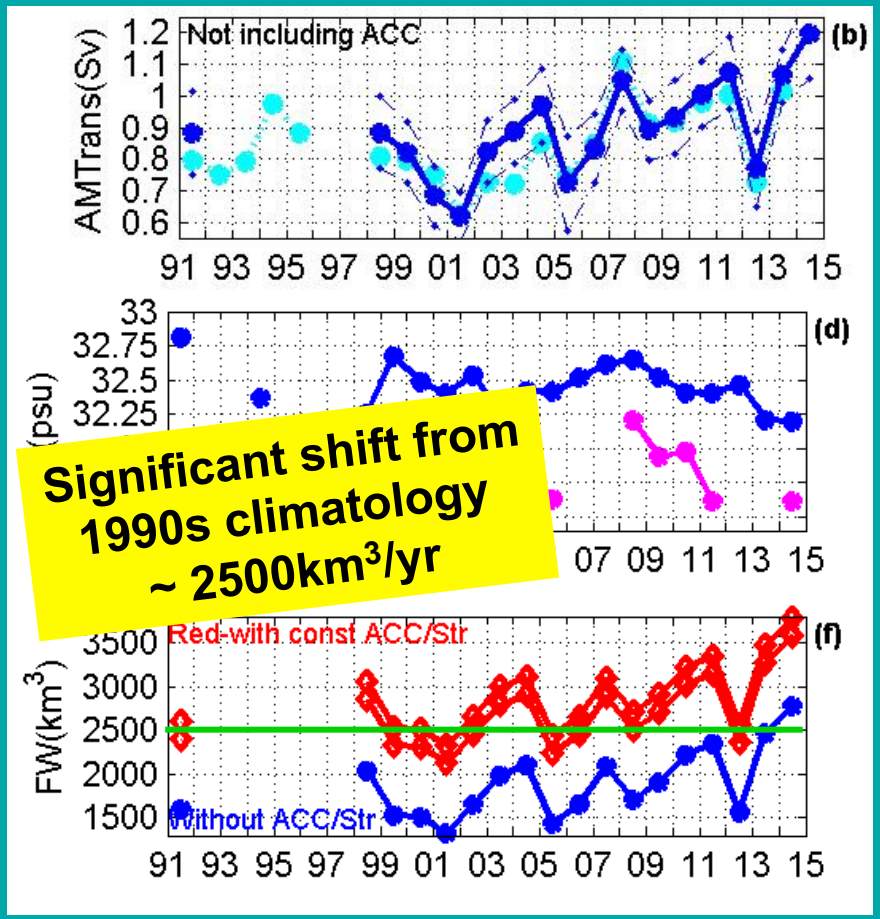
(i.e. can't infer from the wind, though wind ~ 50% hourly variability)

- What sets pressure head?
- Still need moorings

Woodgate et al., in prep

Freshwater flux increase by ~ 40%, mostly due to increased flow





Significant shift from 1990s climatology ~ 2500km^3/yr

Blue=A3, Magenta=A4, Cyan=A2

Woodgate et al., in prep

Freshwater flux relative to 34.8psu

2001 ~ 2000-2500km^3

2014 > 3500km^3

(assuming constant ACC and stratification)

= 90% driven by transport change

= Decadal change (~ 1000km^3),

- about twice decadal variability in

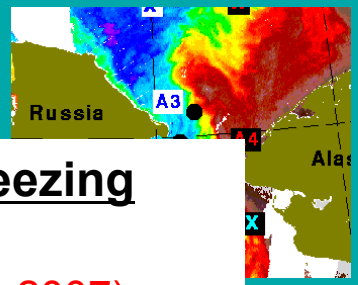
Net precipitation

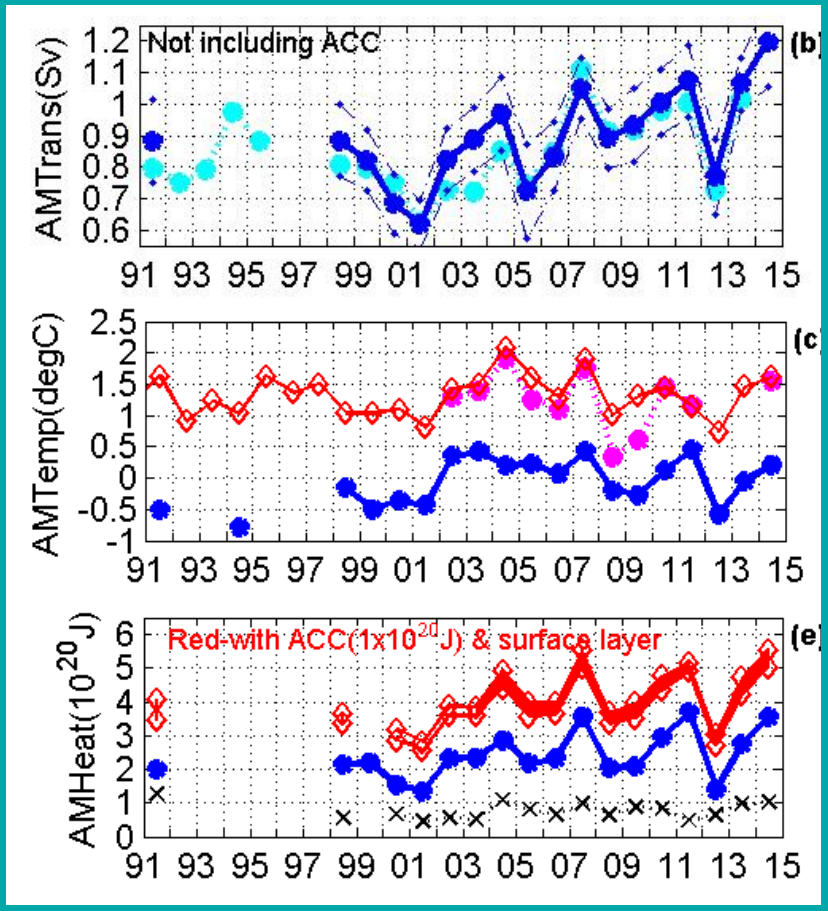
(~ 500km^3, Serreze et al, 2006)

Russian Rivers

(~400km^3, Shiklomanov and Lammers, 2009)

~ 60% increase in heat flux from 2001 - 2014





Blue=A3, Magenta=A4, Cyan=A2
Red Diamonds=SST

Woodgate et al., GRL 2012, updated

Heat flux relative to Tfreezing

2001 ~ 3×10^{20} J

2014 ~ 5×10^{20} J (close to 2007)

(assuming SST surface layer and constant ACC)

≡ melting 1-2x10^{6}km^2 of 1m ice

≡ 2-4W/m^2 over half Arctic

(Arctic surface fluxes ~ -2 to 10 W/m^2, Serreze et al, 2007)

~ 1/3rd Fram Strait oceanic heat

(Schauer et al, 2008)

= ~ half due to transport change, rest LOWER layer temperature change

= SST change does not match lower layer T change.

(SST cannot predict change)

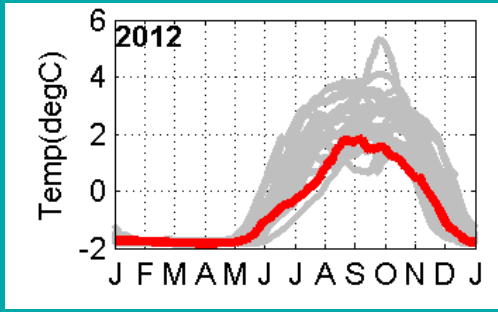
= Some indication perhaps
Lower layer warm waters re
strait earlier (~1.6±1.1 days/year)
(possibly due to increased flux)

2012 low in Transport AND temperature

Why is 2012 so different?

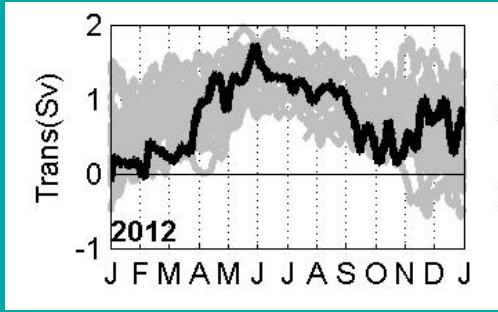
2012

A3 Temp (degC)
smoothed



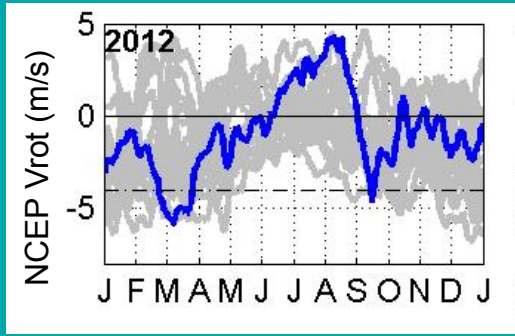
Low temperatures throughout the summer

A3 Trans (Sv)
smoothed



Extreme low transports in Jan-March

NCEP Wind vel (m/s)
smoothed
H330deg



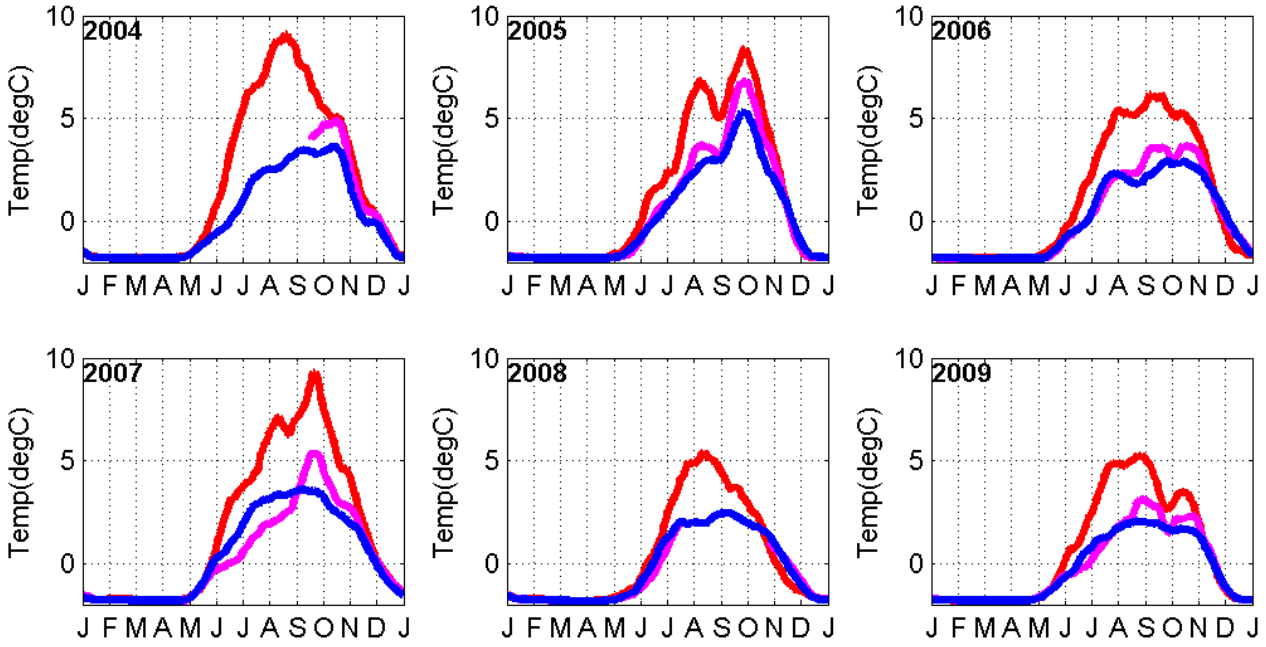
… but winds reasonably normal

Gray = 1990-2014

Properties and arrival of the Alaskan Coastal Current (ACC)

30d smoothed temperature data

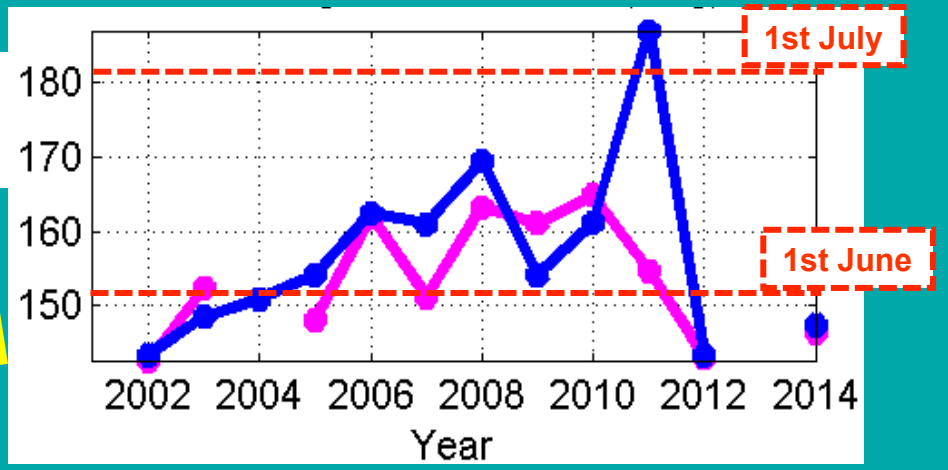
A3
A2 A4



ACC (A4) can be 8 degC warmer than central strait (A2, A3)

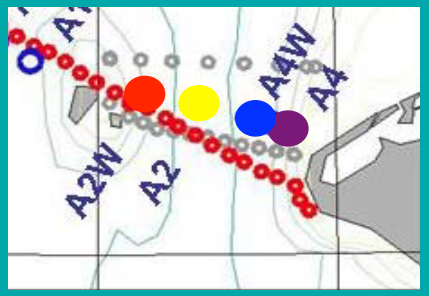
One metric for ACC arrival (JD when A4 one degree warmer)

ACC arriving later in late 2000s?

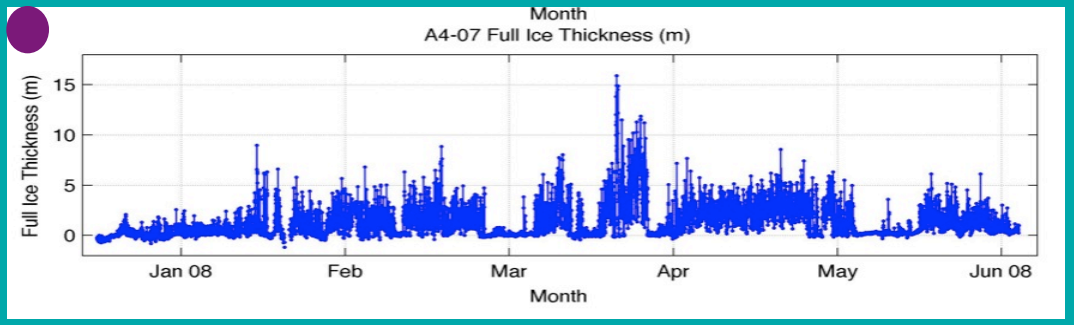


Quantifying ice thickness and fluxes

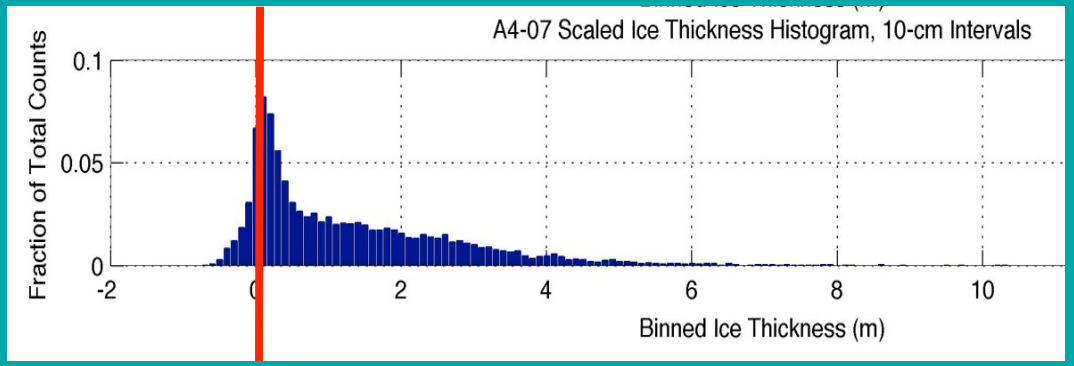
Travers (2012) thesis - use ADCP data for ice thickness, velocity and flux (examples from 2007).



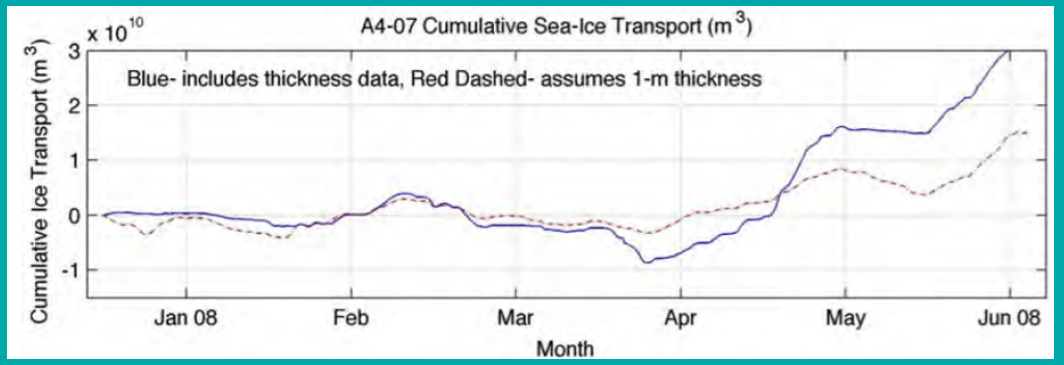
Time series of ice thickness
(errors only slightly greater than ULS)



Ice thickness distribution



Combine with sea-ice velocity to give sea-ice FLUX
(often initially Southward in winter)

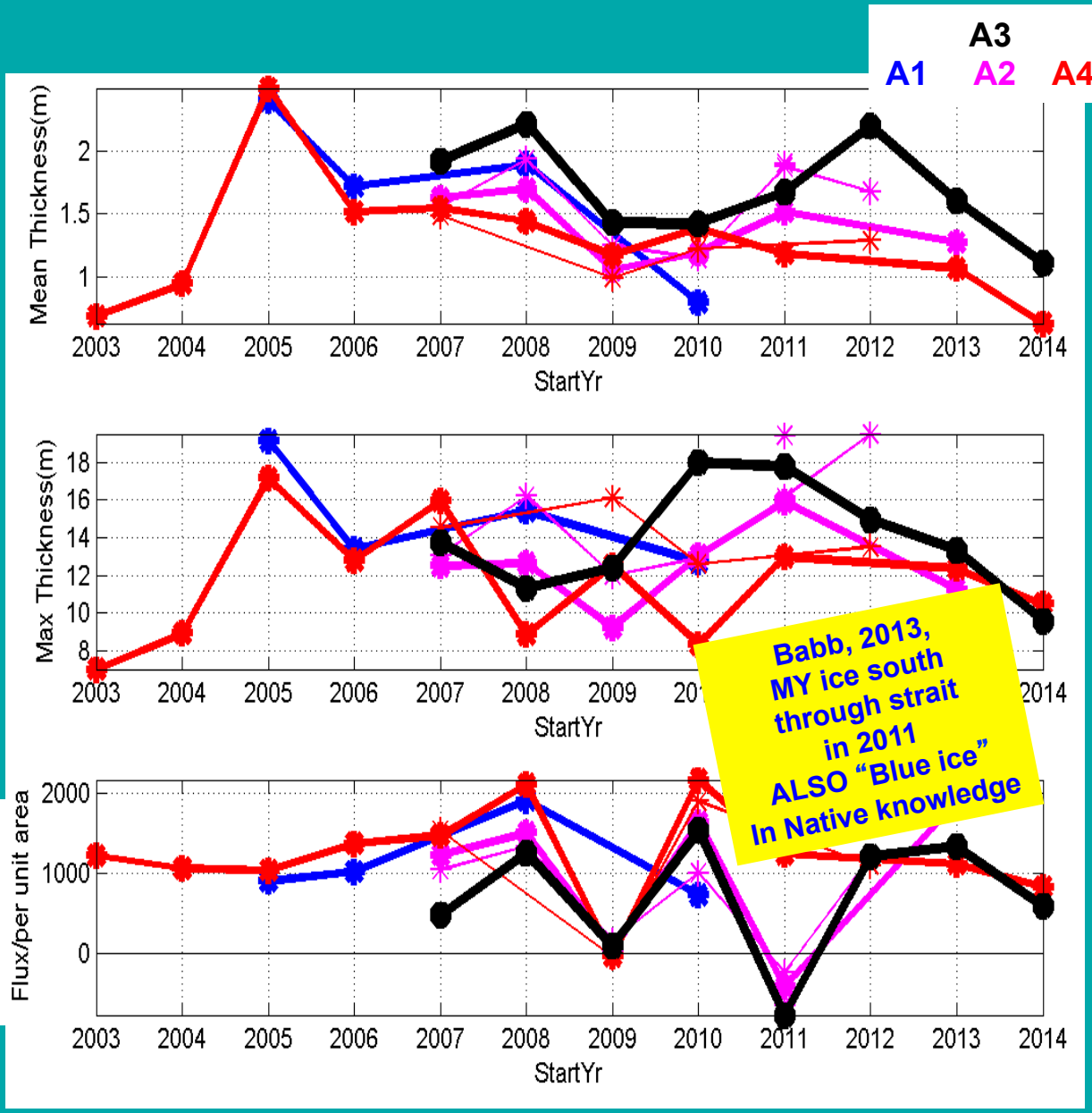


Quantifying ice thickness and fluxes … interannually

Annual Mean Sea-ice Thickness (m)
<1m to >2m

Maximum Sea-ice Thickness (m)
<8m to >18m

Annual Sea-ice Flux
+2 units (i.e., northward)
-1 unit (i.e., southward)



psc.apl.washington.edu/BeringStrait.html

ttle Diomede Island, middle of the Bering Strait

BERING STRAIT: Pacific Gateway to the Arctic

Rebecca Woodgate, Knut Aagaard
University of Washington, USA
Tom Weingartner, Terry Whitledge
University of Alaska, Fairbanks, USA
Igor Lavrenov
Arctic and Antarctic Research Institute, Russia
Corresponding author: Rebecca Woodgate (woodgate@apl.washington.edu)

NSF-Polar Programs

ONR High Latitude

NOAA Arctic Research
RUSALCA

Back to High Latitude Dynamics

BERING STRAIT BASICS

Bering Strait Basic Facts

- *WHY* is the Bering Strait throughflow

2007-2

AON Products:
- Seasonal climatology
- Annual mean transports, heat and freshwater fluxes
- Monthly mean T, S, Velocity ..
- Monthly mean transports, heat and freshwater fluxes ..
- Higher time resolution?
- Other products?

RECENT PUBLICATIONS

A Synthesis of Year-round Interdisci
Measure

through The Main Oceanic Gateways to the Arctic Ocean Beszczynska-Moeller et al., Oceanography, 2011.

The 2007 Bering Strait Oceanic Heat Flux and anomalous Arctic Sea-ice Retreat Woodgate et al, GRL, 2010

RESEARCH EXPEDITIONS

** *Bering Strait 2015* *Live Cruise BLOG* **

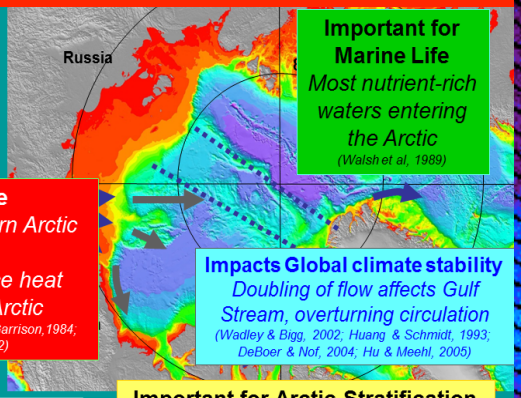
Norseman II 2015 (July)
Norseman II 2014 (June/July)
Norseman II 2013 (July)
Khromov 2012 (July)
Khromov 2011 (July)
Khromov 2010 (July/August)
Khromov 2009 (Aug/Sept)
Lavrentiev 2008 (Oct)
Sever 2007 (Aug/Sept)
Sir Wilfrid Laurier 2006 (July)
Sir Wilfrid Laurier 2005 (July)
Alpha Helix 2004 (Aug/Sept)
Alpha Helix 2003 (July)
Alpha Helix 2002 (June)
Alph
Alpha

Also NODC

DATA ACCESS
GOTO DATA ARCHIVE

Influences Bering, Chukchi, Arctic and GLOBAL climate

... influences ~ half of the Arctic Ocean ... and beyond



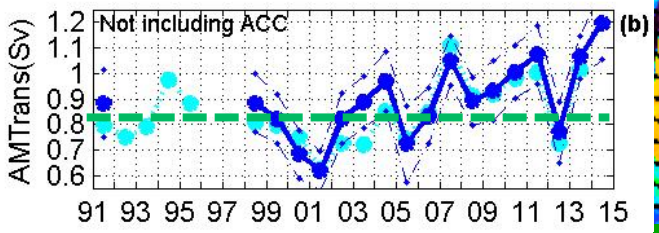
Important for Marine Life
Most nutrient-rich waters entering the Arctic
(Walsh et al, 1989)

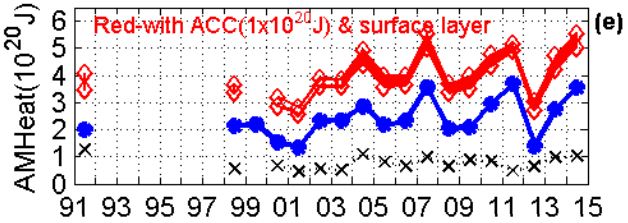
Heat to melt ice
In spring, trigger western Arctic melt onset
Year-round subsurface heat source in ~ half of Arctic
(Paquette & Bourke, 1981; Ahlnäs & Garrison,1984; Woodgate et al, 2010; 2012)

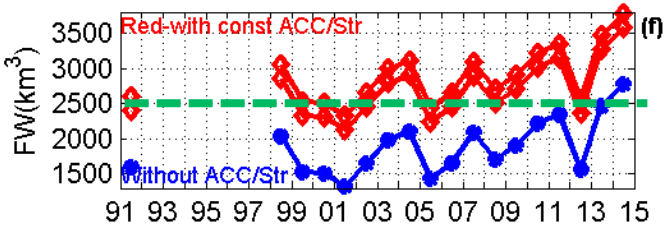
Impacts Global climate stability
Doubling of flow affects Gulf Stream, overturning circulation
(Wadley & Bigg, 2002; Huang & Schmidt, 1993; DeBoer & Nof, 2004; Hu & Meehl, 2005)

Significant part of Arctic Freshwater Budget
~ 1/3rd of Arctic Freshwater
Large (largest?) interannual variability
(Wijffels et al, 1992; Aagaard & Carmack, 1989; Woodgate & Aagaard, 2005)

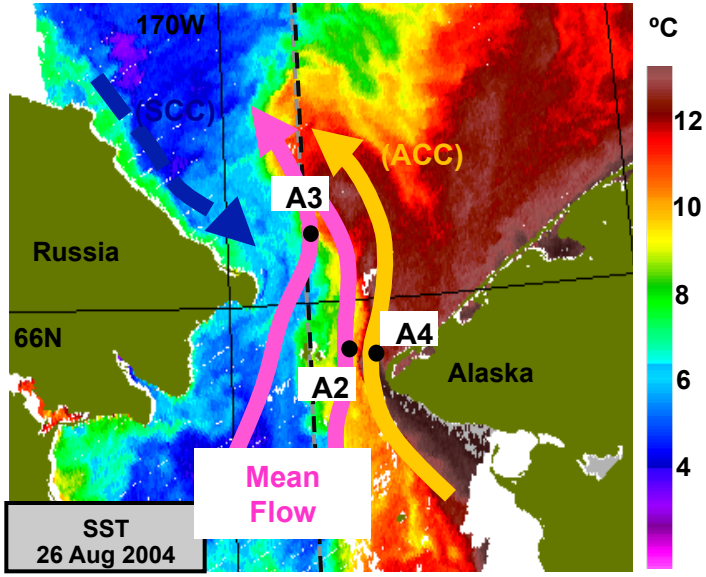
Important for Arctic Stratification
In winter, Pacific waters (fresher than Atlantic waters) form a cold (halocline) layer, which insulates the ice from the warm Atlantic water beneath
(Shimada et al, 2001, Steele et al, 2004)







A 3 US mooring array to quantify volume, heat, freshwater and sea-ice fluxes from 1990-present



What can be done with the data?

== Water properties, fluxes, ice data
== Interannual Change (~70% in volume)
- large (increasing), driven by far field
== Understanding anomalous years
== Small scale features
== What products do YOU want?

psc.apl.washington.edu/BeringStrait.html